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“A 2D Computational Model of a ThermoMagnetic Device”

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Agenda

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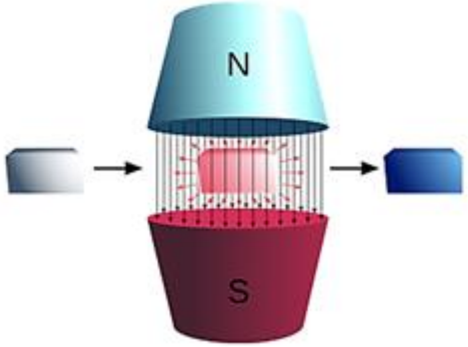
Introduction



Primary energy consumption is increasing constantly

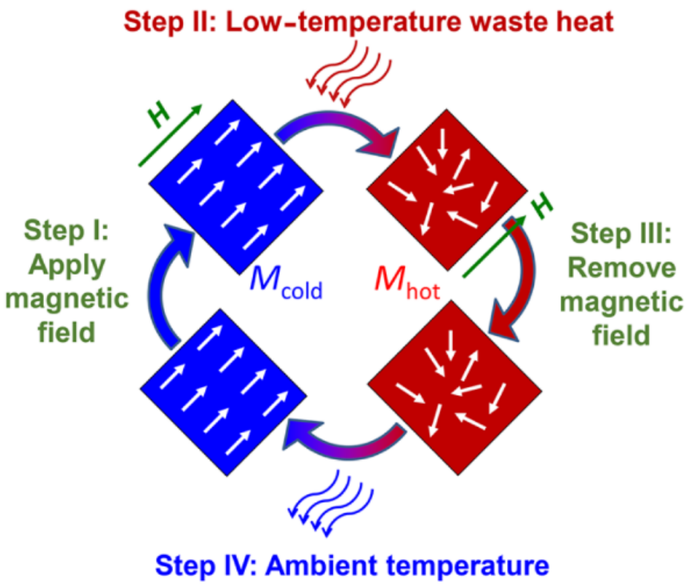
- Thermal losses up to 72% of energy produced [1],
  45% are waste heat below 100ºC (low-grade heat) [2]
  - High global warming effect [3]

Environmental-friendly alternative

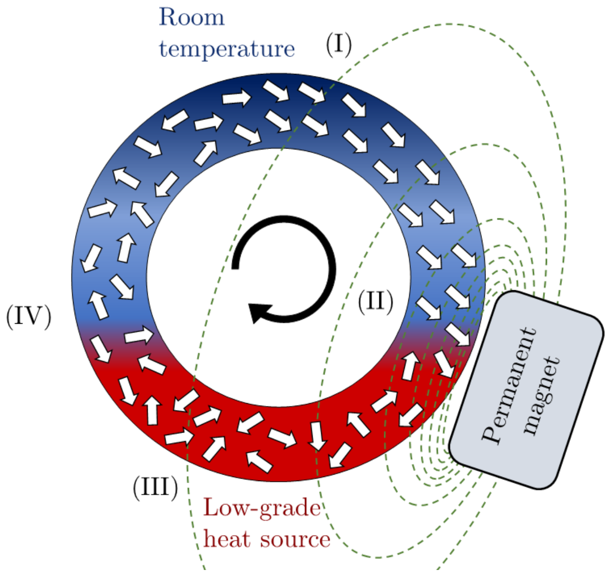
- Thermo-Magnetic Generation (TMG) [4]
  - Converting low-grade waste heat into usable energy
    High potential efficiency and cost-effective [5][6]
  - Based on functional materials with magnetocaloric properties (MCM) [7]

Introduction

This work aims to study the performance of a Thermo-Magnetic Energy Converter (TMEC) for harvesting low-grade heat waste, using a computational model developed in COMSOL Multiphysics®



Thermo-Magnetic Cycle [8]



Thermo-Magnetic Motor, with $Ni_{48}Mn_{36}Sn_{16}$ as MCM

Solution with COMSOL Multiphysics®. Governing Equations

Constitutive relations for the magnetic field generated by the magnets, using their magnetization

$$\boldsymbol{H} = -\nabla V_m$$

$$\boldsymbol{B} = \mu_0(\boldsymbol{H} + \boldsymbol{M}) \quad ; \quad \nabla \cdot \boldsymbol{B} = 0$$

$$-\nabla \cdot (\mu_0 \nabla V_m - \mu_0 \boldsymbol{M}) = 0$$

Energy-balance relation for heat transfer in solids and fluids

$$\rho C_p \boldsymbol{u} \cdot \nabla T + \nabla \cdot (-k \nabla T) = Q_{in}$$

Solution with COMSOL Multiphysics®. Governing Equations

System angular acceleration based on Kelvin force and MCM mass magnetization [9]

$$\boldsymbol{F} = \mu(\boldsymbol{M} \cdot \nabla)\boldsymbol{H}$$

$$\tau = r_{avg}F$$

Momentum

$$\alpha = \frac{\tau}{I}$$

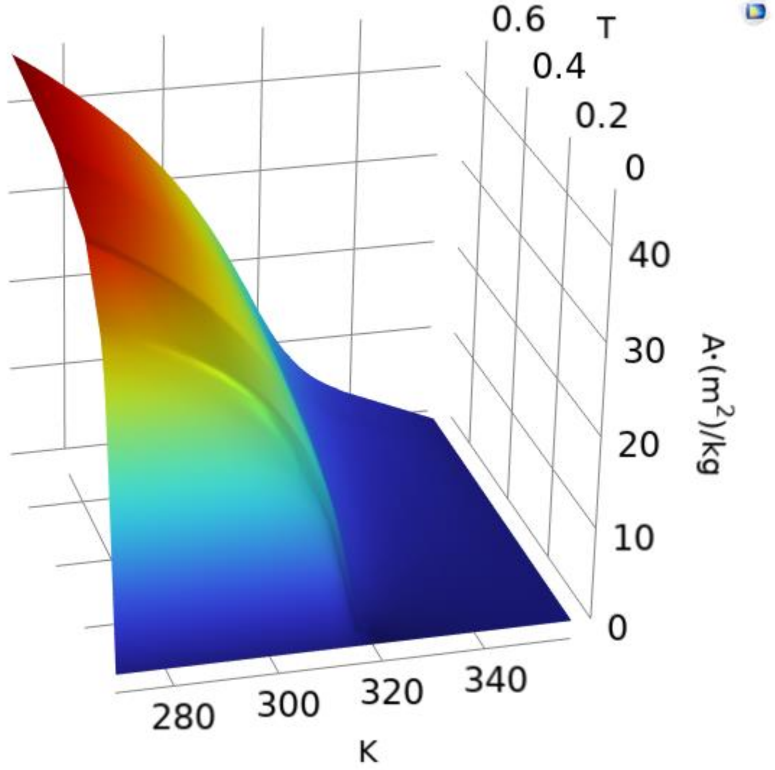
Angular acceleration

$$I = \frac{1}{2}m\left(r_{ext}^2 + r_{in}^2\right)$$

Moment of inertia

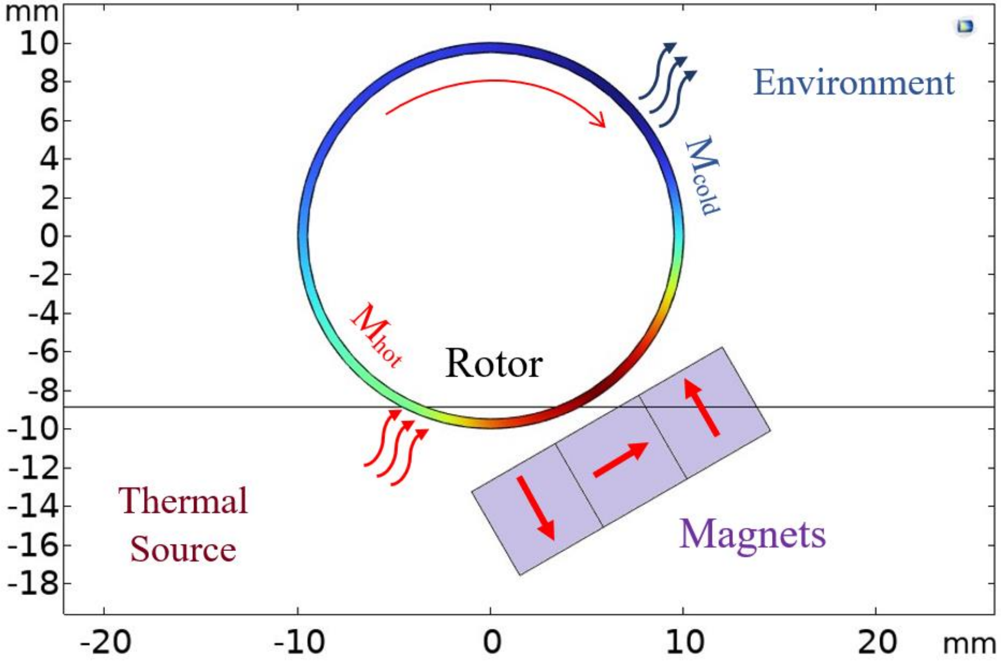
$$w(t) = w(t - dt) + \alpha(t)dt$$

Angular velocity



$Ni_{48}Mn_{36}Sn_{16}$ *magnetization per unit mass*

Solution with COMSOL Multiphysics®. TMEC modeling

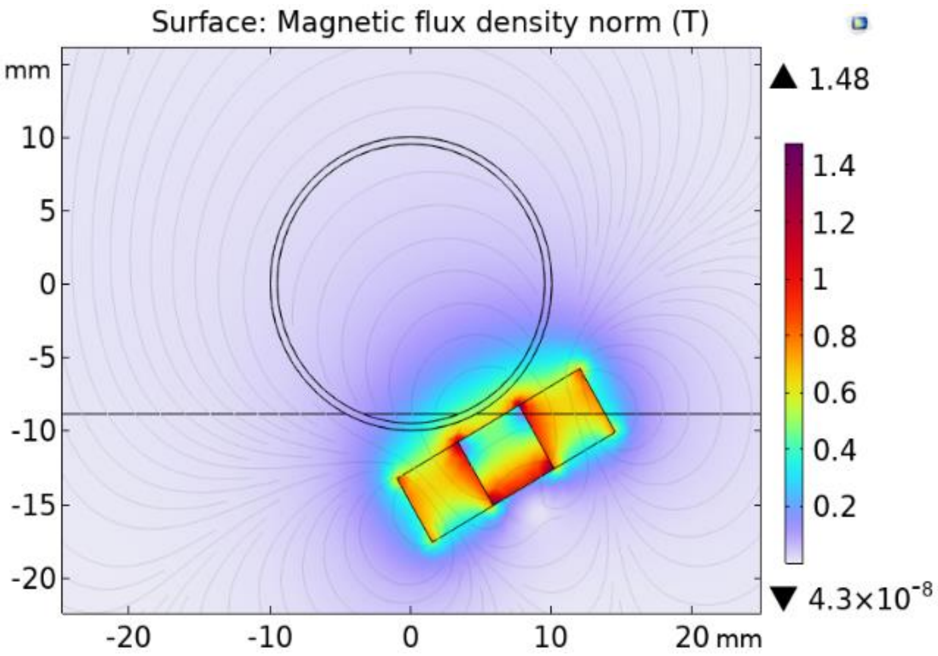


Thermo-Magnetic Device geometry and boundary conditions

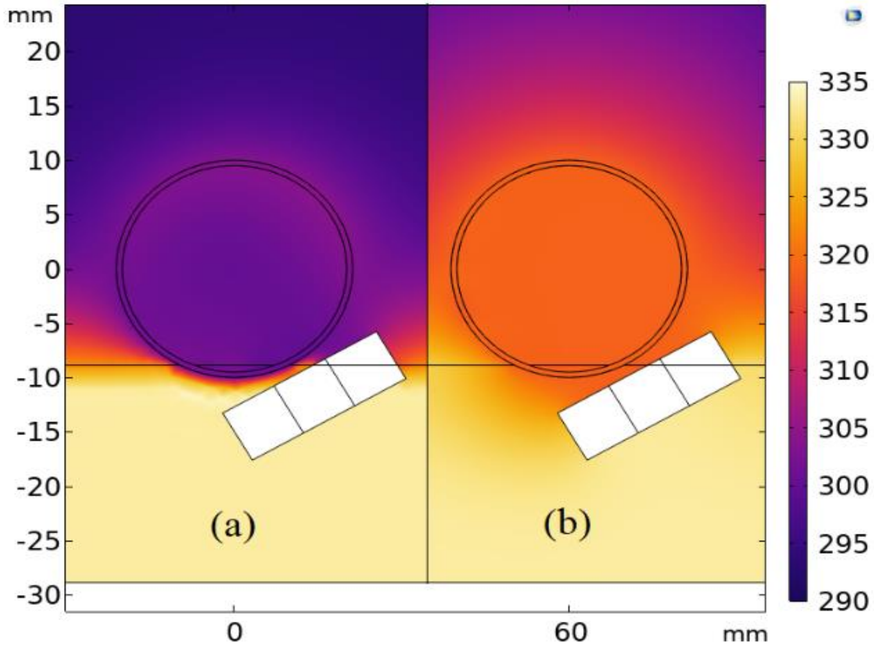
Initial Conditions and working parameters

Parameter	**Value**
NdFeB magnets magnetization	900 kA/m
$Ni_{48}Mn_{36}Sn_{16}$ permeability	$1.237e^{-6}$ N/A^2
$Ni_{48}Mn_{36}Sn_{16}$ conductivity	20 W/(m·K)
$Ni_{48}Mn_{36}Sn_{16}$ heat capacity	500 J/(kg·K)
$Ni_{48}Mn_{36}Sn_{16}$ density	7900 kg/m^3
Rotor total mass	3 g
Low-grade thermal source T_{hot}	333,15 K
Environment T_{Cold}	293,15 K
Rotor surface submerged	10%

Results and discussion

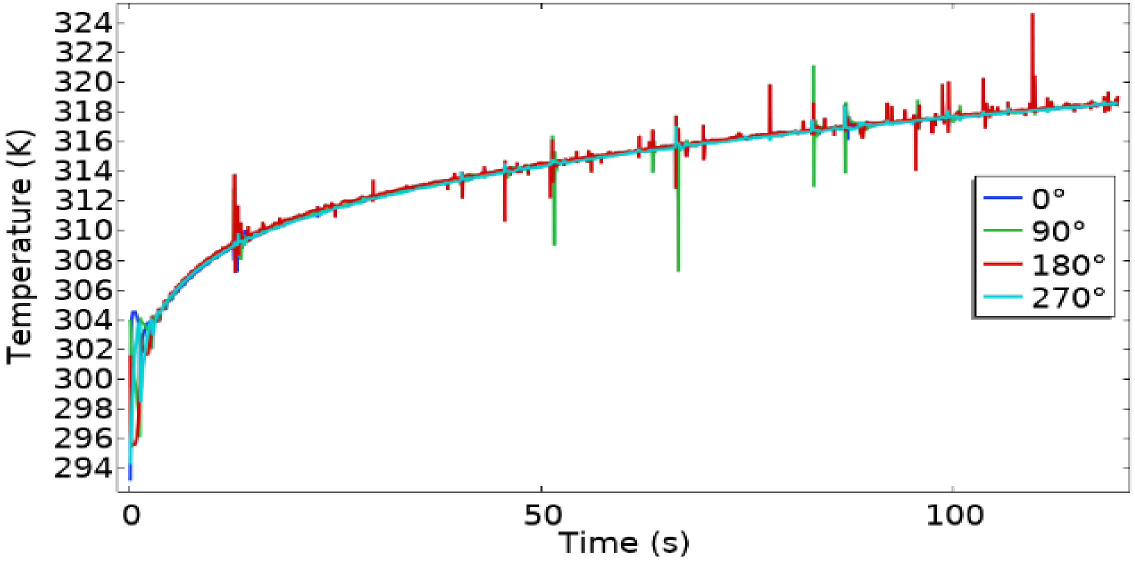


Magnetic Field generated by magnets array

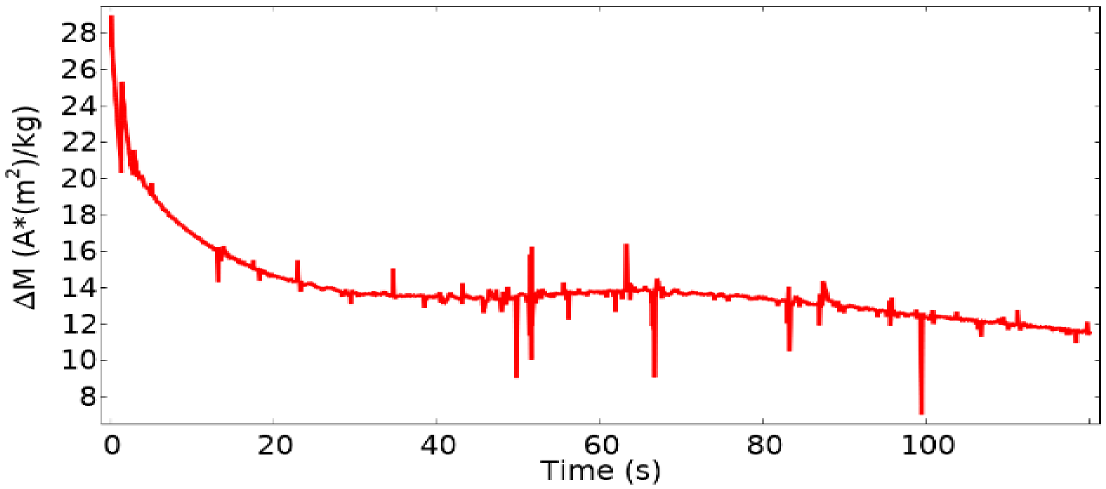


Temperature profile over the TMEC model at (a) 2.5s, and (b) 120s.

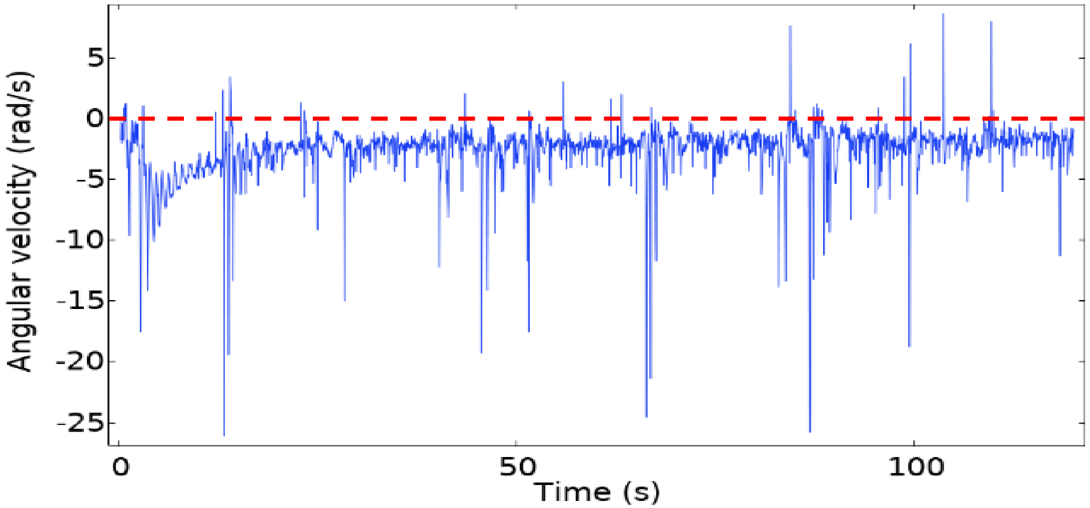
Temperature gradient at different angles along the MCM rotor



Results and discussion



Change in the $Ni_{48}Mn_{36}Sn_{16}$ rotor magnetization per unit mass over time



Rotor angular velocity over time

Material Efficiency

$$\eta = \frac{\mu_0 (M_{cold} - M_{hot}) H}{Q_{in}}$$

$$\boxed{\eta = 4{,}41\%}$$

But for [8]

$$\eta_{Carnot} = \frac{\Delta T}{T_{hot}} = 12{,}007\%$$

as the upper theoretical limit, TMEC achieved a 36,6% of the benchmark value, which still is competitive.

Conclusions

- The performance of a Thermo-Magnetic Energy Converter (TMEC) has been evaluated in terms of angular velocity, material magnetization, and efficiency using a 2D-model of a thermomagnetic motor based on magnetocaloric materials.
- The TMEC, with a $Ni_{48}Mn_{36}Sn_{16}$ Heusler compound rotor, exhibits a low efficiency performance due to the constant heating of the material, which halts the change in its magnetization, but if compared with the theoretical upper efficiency limit, still is a viable and competitive alternative for harvesting low-grade waste heat.
- The computational results obtained with COMSOL Multiphysics® are encouraging for future studies where certain parameters of the model can be varied to optimize the response of different magnetocaloric materials or the overall performance of the TMEC.

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Acknowledgments

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